Comprehensive Forced Response Analysis of J2X Turbine Bladed-Discs with 360 Degree Variation in CFD loading

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The temporal frequency content of the dynamic pressure predicted by a 360 degree computational fluid dynamics (CFD) analysis of a turbine flow field provides indicators of forcing function excitation frequencies (e.g., multiples of blade pass frequency) for turbine components. For the Pratt and Whitney Rocketdyne J-2X engine turbopumps, Campbell diagrams generated using these forcing function frequencies and the results of NASTRAN modal analyses show a number of components with modes in the engine operating range. As a consequence, forced response and static analyses are required for the prediction of combined stress, high cycle fatigue safety factors (HCFSF).

Cyclically symmetric structural models have been used to analyze turbine vane and blade rows, not only in modal analyses, but also in forced response and static analyses. Due to the tortuous flow pattern in the turbine, dynamic pressure loading is not cyclically symmetric. Furthermore, CFD analyses predict dynamic pressure waves caused by adjacent and non-adjacent blade/vane rows upstream and downstream of the row analyzed. A MATLAB script has been written to calculate displacements due to the complex cyclically asymmetric dynamic pressure components predicted by CFD analysis, for all grids in a blade/vane row, at a chosen turbopump running speed. The MATLAB displacements are then read into NASTRAN, and dynamic stresses are calculated, including an adjustment for possible mistuning. In a cyclically symmetric NASTRAN static analysis, static stresses due to centrifugal, thermal, and pressure loading at the mode running speed are calculated. MATLAB is used to generate the HCFSF at each grid in the blade/vane row. When compared to an approach assuming cyclic symmetry in the dynamic flow field, the current approach provides better assurance that the worst case safety factor has been identified. An extended example for a J-2X turbopump component is provided.